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Design of Wang shape neutralization line antenna to reduce the mutual coupling in MIMO antennas

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Abstract
The making of a Wang shape neutralization line is proposed in this article. A micro strip fed dual-band polarized antenna having two slits cut on left and right side of the patch is inserted to achieve neutralization between the two patches. The proposed structure has a dimension of 60 mm × 40 mm patches, optimization procedure of 0.09 λ_0 is chosen to reduce the mutual coupling and to maintain the spacing between the two radiators. For impedance matching a microstrip feed line to a wang shape neutralization line antenna is excited by a 50 Ω to generate wider operating dual-bands. By congruously embedding small rectangular slots in the patch, the antenna unveils dual-band linear polarization. The dual-band proposed antenna mechanism, surface current distribution, parametric study; step by step antenna design is discussed here. This antenna is suited for WiMAX, 2.6 GHz and C-band, 6.1 GHz applications.

Keywords Neutralization line · Mutual coupling · Channel capacity · TARC

1 Introduction

The most popular and widely used modern satellite/mobile/wireless devices like WLAN, WiMAX, and universal mobile telecommunications service (UMTS), international telecommunication unions (ITU), X-band satellite systems and intelligent transport system (ITS) have been observed in linearly polarized printed antennas. These systems having certain advantages like reduction of polarization mismatch suppression in the propagation losses and effects in multipath propagation. As these issues could be resolved with a single radiated MIMO antenna with dual-band LP (Linearly polarized) functionality covering all communication bands, it has drawn the attention of researchers and academicians. Different approaches like LP printed antennas were studied using different techniques to obtain the linear polarization. To meet the requirement of the above mentioned applications a MIMO radiator (antenna) seems to be a better choice but MIMO poses a great challenge in the form of size, capability of multi-bands, performance of diversity antenna and large mutual coupling. In modern days different MIMO antennas [1–20] are reported among the antenna elements to reduce the mutual coupling and provide improved in diversity performance and wideband characteristics. In [1], reports a technique two parasitic strips to reduce the mutual coupling, a compact cavity-backed 60 GHz array antenna using EBG structures to reduce mutual coupling − 36 dB and occupied an area 55 × 60 mm^2 [2], an antenna consisting 4-channel with compact in size having S_{12} around − 26 dB [3], for multi-band applications to enhance the bandwidth of pentagonal antenna is reported [4] with an operating range of frequency 3.1–5.0 GHz maintain an isolation less than − 20 dB. In [5] a compact slotted rectangular and hexagonal monopole radiators design in UWB applications. By consider defect in ground structure with a polygon shape to reduce the isolation [6], for the applications of WiMAX and WLAN a tri-band structured MIMO antenna with S_{12} is equal to 31 dB reported in [7]. A very small compact planar 60 × 30 mm^2 MIMO tri-band diversity

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antenna having S_{12} of -37 dB reported [8], a tri-band ACS fed antenna enlist the radiating patches like L and C shape applicable to wireless applications [9]. For multiband MIMO applications a CPW reconfigurable antenna [10] was reported, a compact rectangular monopole stubs loaded antenna is used for [11] WiMAX or WLAN applications. A low-profile [12] folded SRR are used to reduction of isolation between patch antennas, inserting an I-section microstrip line between the E-shaped patch antenna to reduce mutual coupling [13] is investigated here, CP patch array isolation minimized by insertion of an angular offset elements is observed in [14], a wang-shape design having rhombus lattice and offset elements are arranged with small shorting pins reduces the isolation less than -15 dB observed [15]. Similarly, different approaches [16–20] like slot antenna, waveguide metamaterial, meander line resonators, $\lambda/4$ slots and DGS are reported.

The novelty in the proposed wang shape neutralization line model, a neutralization line is inserted between the two rectangular patches to reduce the mutual coupling (isolation) greatly compared to existing systems mentioned in the literature achieve a dual-band ranges. This neutralization line considered in the form of width and length of rectangular microstrip patch. This type of proposed structure having the major need in current wireless communication system such as enhancing the bandwidth, good gain, compactness and low loss antenna. Similarly, to improve the mutual coupling of this MIMO structure, neutralization line between the patches with 2 mm width inserted. From the theoretically analysis observed that neutralization line transfer of some amount of current to the first radiator and delivers to second radiator to cancel out the coupling between the radiators. It was identified that by adding the technique of neutralization line in the current design, the radiator port isolation can be very effectively enhanced compared with without neutralization technique. The radiators are not definitely targeted on the WiMAX, 2.6 GHz UMTS and C- band 6.1 GHz for possible applications. The technique of neutralization line method allows the picked up the signals from one type of antenna to another type of antenna produces that an opposite mutual coupling to the previously existing one observed that without using neutralization line technique having low value of mutual coupling produced at different frequencies is achieved (Table 1).

2 Antenna design

A dual-band wang shape neutralization line antenna is designed and fabricated with a very low-cost substrate of FR4 have $\varepsilon_r = 4.4$, thickness 1.6 mm and loss tangent parameter 0.002. The dimensions of the prototype are 60×40 mm^2. Numerical analysis, simulation and design of antenna structure are done by computer simulation technology. To obtain the characteristic impedance 50 Ω, the proposed structure having a geometry of neutralization line width 'h' and strip of microstrip feeding 'X_1' along with a ground plane is taken into consideration. To illustrate the wang shape neutralization MIMO antenna evolution and functionality have been depicted in Figs. 1, 2. Figure 1 shows the different evolution stages of wang shape NL antenna and its corresponding effective variations of microstrip width and neutralization widths is shown in Fig. 2. From the Fig. 1 the geometry present of Antenna 1 is of basic rectangular microstrip patch structure which produces a S_{11} of -10.13 dB at 2.6 GHz & -48 dB at 6.1 GHz. In the second evolution stage two rectangular slots are cut by both length and width to the left side of the patch and Antenna 2 is designed which produces a S_{11} of -10.19 dB at 2.6 GHz and -38 dB at 6.1 GHz. In the third evolution stage two more rectangular slots are cut along width and length along right side of the patch and Antenna 3 is designed which produces a S_{11} of -14.23 dB at 2.6 GHz and -34 dB at 6.1 GHz.. The fourth evolution stage, the substrate is increased to double the first case resulting in the formation of Antenna 3, it is transformed within the substrate with a separation between the patches at 0.05 λ_0 to form Antenna 4 which produces a S_{11} of -42 dB at 2.6 GHz and -15 dB at 6.1 GHz. In the final evaluation stage, a neutralization line is inserted between the patches to form a wang shape neutralization line design. Antenna 5 is proposed structure to minimize the mutual coupling connecting the antennas of the final design which produces a S_{11} of -48 dB at 2.6 GHz and -16.52 dB at 6.1 GHz. Final results show the formation of wang shape MIMO antenna with feeding mechanism and a dual-band operation with a range of 2.2 GHz to 3.3 GHz and 5.6 GHz to 6.3 GHz. The wang shape antenna is used in the applications of WiMAX and C-band applications. Here we observed that there is a variation in S_{11} changing from Antenna 4 to Antenna 5 difference of -6 dB at 2.6 GHz and -1.52 dB at 6.1 GHz. The technique of adding neutralization line between the radiating

Table 1 Geometry of proposed wang shape neutralization line antenna

Design parameters	L	W	L_P	W_P	a	b	c	d	e	f	g	h	i	j	k	X_1
Value(mm)	60	40	20	20	18	40	2	2	3	3	4	2	4	4	4	5

Fig. 1 Evolution stages of wang shape neutralization line MIMO antenna

(a) Antenna 1   **(b)** Antenna 2   **(c)** Antenna 3

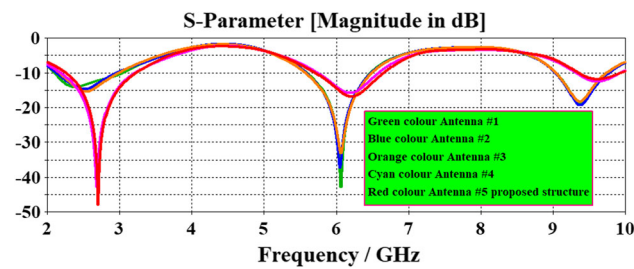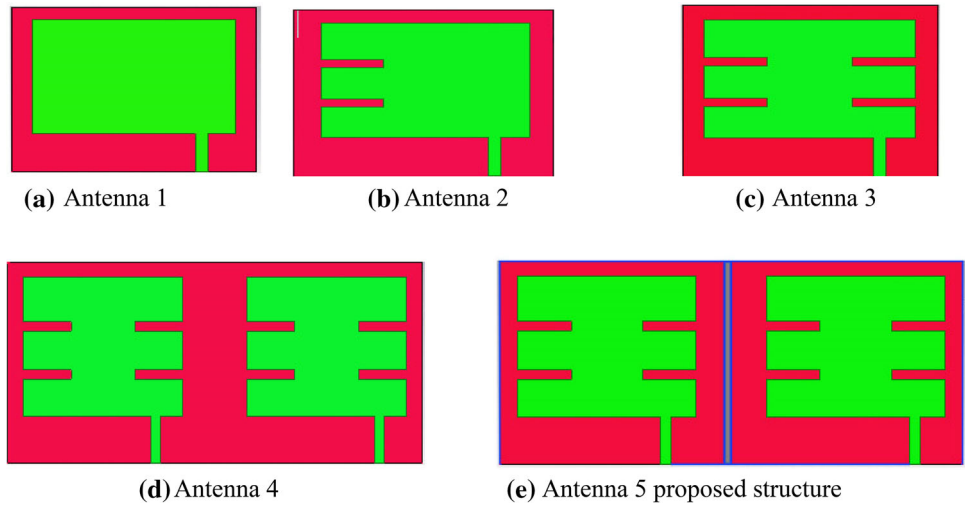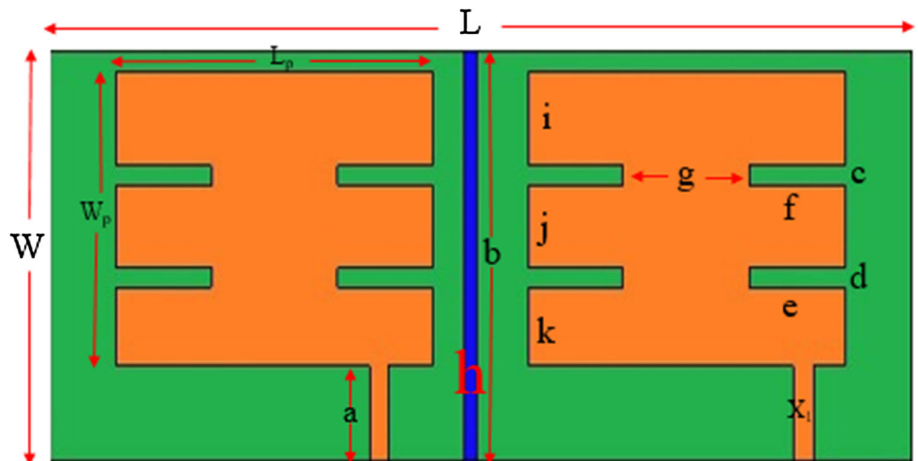**(d)** Antenna 4   **(e)** Antenna 5 proposed structure

Fig. 2 S_{11} comparison of different structures of antennas to Fig. 1

patches a little bit of variations in S_{11} but it mainly effects the parameter mutual coupling (S_{12}). The method creates an alternative current directions as illustrated due to this condition the surface current will not flowing from port 1 to port 2 via the common point of the ground plane. Neutralization line method plays an important role to improving the mutual coupling (isolation) particularly in the lower band of frequencies. The geometric representation of wang shape neutralization line structure is depicted in Fig. 3. The front plane is printed on the proposed structure and the

ground plane printed another side of the substrate that is the bottom side. Due to variation of different parameters in this structure like 'h' and 'X_1' the improvement in return loss as well as reduction of mutual coupling and improvement in wider bandwidths is observed. If optimization procedure is taken into consideration, the value at h = 2 mm and X_1 = 2 mm of wang shape neutralization line design antenna produced better results. Table 2 shows the comparison for existing approaches with respect to the proposed wang shape neutralization line method (Fig. 4).

3 The theoretical analysis

From the S_{11} graph observed that dual-band characteristics of antenna resonance can be identified that at 2.6 GHz and 6.1 GHz. A major contributing factor component for dual-band of resonant frequencies at f_1 = 2.6 GHz and f_2 = 6.1 GHz shown. S_{11} curves simulation is obtained by cutting

Fig. 3 Geometry symbols representation of Wang shape Neutralization line

Table 2 Comparison between reported structures and proposed wang shape neutralization line

Ref.	Size (mm^2)	S_{11}(dB)/Return loss	S_{12}(dB)/Mutual coupling	f_L–f_H (GHz)
Shinde [1]	78 × 60	− 32	− 13.4	2.1–2.6
Lu and Lin [2]	55 × 60	− 28	− 36	58.5–60
Ghosh [3]	75 × 70	− 41	− 26	2.1–3.15
Shinde and Jayashree [4]	87 × 85	− 36	− 22	3.1–5.0
Naidu and Kumar [5]	20 × 20 (SISO)	− 42	–	2.9–3.4
Farahbakhsh [6]	72 × 55	− 35	− 26	3.1–5.0
Fang and Mi [7]	72 × 55	− 32	− 31	2.0–5.0
kumar and Sharma [8]	60 × 30	− 41	− 37	2.0–5.0
Shahmirzadi [10]	87 × 85	− 36	− 22	3.1–5.0
Kumar and Sharma [11]	78 × 60	− 26	− 14	3.1–10.6
Habashi and Nourinia [12]	64 × 32	− 35	− 25	3.1–10.5
Ghosh [13]	88 × 70	− 35	− 15	3.1–10.6
Chung [14]	91 × 38	− 32	− 17	3.1–10.6
Pratap and Shinde [16]	35 × 40	− 32	− 16	3.1–10.6
Yang and Liu [17]	55 × 39	− 46	− 21.5	3.1–8.0
Alsath and Kanagasabai [18]	91 × 48	− 48	− 19	3.1–10.0
Zuo and Yin [19]	95 × 79	− 46	− 21.5	3.1–8.0
Xiao and Tang [20]	77 × 55	− 37	− 16.7	3.1–10.0
Wang shape neutralization line	60 × 40	− 47.9	− 29.09	2.2–3.1
		− 14.49	− 48.17	5.7–6.5

Fig. 4 Fabrication of Wang shape Neutralization line antenna
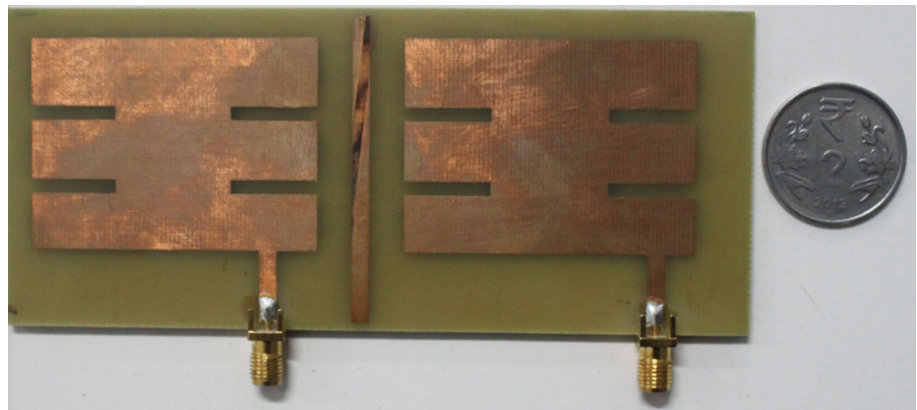
rectangular slots in the patch. From the MIMO design the two resonant lengths can be evaluated as

$$L_1 = L_p + c + f − 0.2 + f + d − (L − 2)/2 \quad (1)$$

$$L_2 = L_p − g − f − e − 4.1 − k \quad (2)$$

For this antenna, the resonant frequency is obtained using Eqs. (3) and (4).

$$f_1 = \frac{c}{L_1 L_p \sqrt{\varepsilon_{r,eff}}} \quad (3)$$

$$f_2 = \frac{c}{L_2 W_p \sqrt{\varepsilon_{r,eff}}} \quad (4)$$

$$\varepsilon_{r,eff} = \frac{\varepsilon_r + 1}{2} \quad (5)$$

here L_p represents the length of the patch, W_p represents the width of the patch, $\varepsilon_{r,eff}$ represents effective relative permittivity substrate obtained by from Eqs. (3). To calculating the effective permittivity, it is considered that wang shape NL having half of the substrate is distributed and remaining half field lines are in air. While evaluating the lengths of proposed structure the average strip value of

widths is considered as 2.5 mm. If the strip is resonated to quarter wavelength resonance frequency comes to 2.6 GHz which is near to simulated resonance frequency, similarly at 6.1 GHz slightly shifted towards the edge of patches due to this reason the simulated frequency just away from the theoretical calculation.

4 The parametric study

4.1 Effect of varying the neutralization line and microstrip feed

The separation gap between the two wang shape patches and microstrip feed of the antenna plays a significant role in producing good return loss, mutual coupling and directivity of Wang MIMO structure. Figure 5 depicts the variation in neutralization line and microstrip feed line for different values of X_1 and h varying 1.6 mm to 2.2 mm, finally obtained a maximum value of S_{11} at $X_1 = 2.0$ mm and h = 2.0 mm. This case obtained impedance bandwidth around 1.1 GHz at 2.6 GHz and 1.8 GHz at 6.1 GHz. Figure 5 indicates effect of parametric analysis on proposed design. It can be observed that from the Fig. 5 'h' value increase at third and fourth resonant frequencies shifted towards increase in the return loss and IBW (Impedance Bandwidth) decrease drastically at h = 2.0 mm is considered the neutralization line.

5 Results and discussion

5.1 S-parameters and VSWR

A wang shape neutralization line antenna is fabricated using PCB prototyping, MITS Eleven Lab, and the proposed prototype structure is depicted in Fig. 4. To validate the performance of wang shape neutralization structure, the parameter S_{11} measured with network analyzer Agilent PNA-N5234A (Fig. 6). The parameters like S_{11}, S_{12} and comparison of S-parameters of simulated and measured values plotted in Figs. 7, 8, 9. From Fig. 7 we can observe
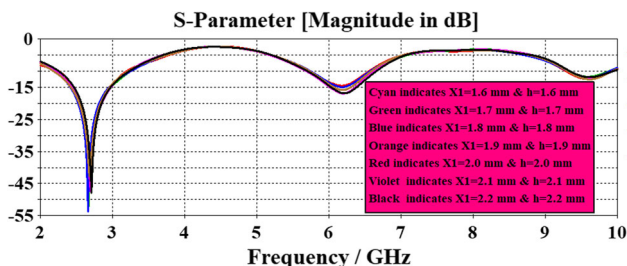

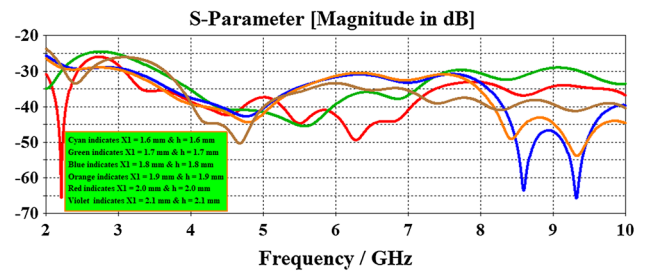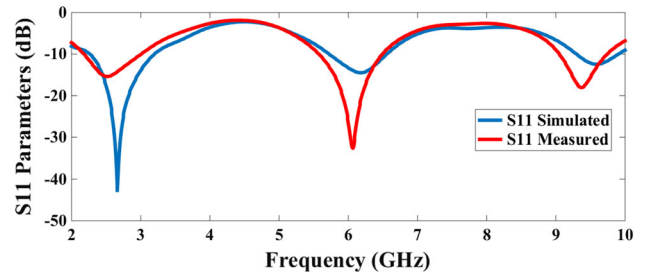Fig. 6 The effect of varying X_1 and h simulated results for S_{12}

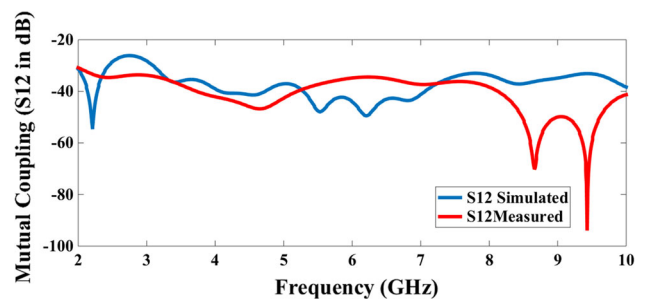Fig. 7 S_{11} comparison of wang shape neutralization line

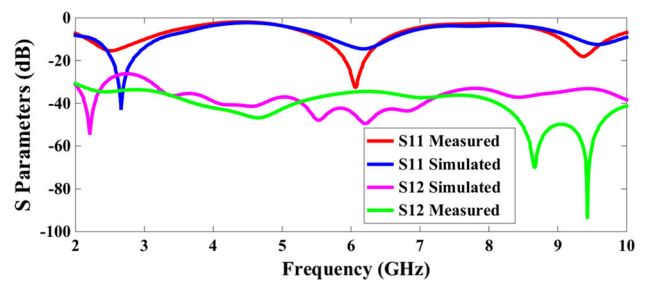Fig. 8 S_{12} comparison of wang shape neutralization line

Fig. 9 S-parameters comparison of wang shape neutralization line

that the measured IBWs (Impedance Bandwidths) below − 10 dB are 1.02 GHz (2.23–3.25 GHz) and 900 MHz (5.70–6.60 GHz). Due to the soldering of SMA connector at the edge of two strips wang shape neutralization line antenna, measurement aligned errors, type of material properties used for simulation and fabrication process, a slight shift in measured and simulated resonant frequencies and bandwidths is observed in terms of S_{11}, S_{12}, S-parameters comparison and VSWR.

Fig. 5 The Effect of varying X_1 and h simulated results for S_{11}

5.2 Surface current distribution and directivity 3D maximum value

To understand the operating mechanism better, one of the parameters that is surface current distribution on the radiating patches at 2.6 GHz and 6.1 GHz is shown in Figs. 10, 11. From the figure it is observed that a larger current distribution is observed in the area of rectangular cut slots area and a lesser current distribution in the feeding line at 2.6 GHz, whereas for the second resonant mode frequency higher current distribution is observed in feeding line and neutralization line. A strong electromagnetic coupling is observed at a frequency at 6.1 GHz, major electric current is produced on the rectangular slots that are attached to the feeding line. The surface current distribution vector at 2.6 GHz port1 is excited and 6.1 GHz, port 2 is excited shown in Figs. 10, 11. The antenna can be recognized when the first port of antenna is excited and second port of the antenna terminated with a characteristic impedance of 50 Ω then the surface vector on the wang shape neutralization line alongside the y-axis is depicted in Fig. 10. Likewise, when first port is matched and second port is excited the distribution of surface vector is depicted in Fig. 11 side of the x-axis. When both of the ports are analogous to surface current perceived that the elements are orthogonally and then generate a first resonant mode at 2.6 GHz. Similarly applied the same procedure the second resonant mode is generated at 6.1 GHz by applying the same procedure. Another parameter to measure here is directivity of the wang shape neutralization line antenna at f = 2.6 GHz is 3.8 dBi, at a frequency of 6.1 GHz the directivity is 5.2 dBi depicted in Fig. 12.

5.3 Radiation patterns for Wang shape NL antenna

From Fig. 13(a, b) shows the radiation patterns measured as well as simulated at dual-band frequencies of 2.6 GHz and 6.1 GHz in the plane of xz considered at θ = 0° and the plane yz considered at ϕ = 90° respectively. It is observed

that the proposed antenna is the antenna under test and horn antenna is considered as reference antenna to measure radiation patterns at 2.6 GHz and 6.1 GHz using anechoic chamber LB-OSJ-20,180-P03. From Fig. 13(a) can be observed that omnidirectional co-polarized pattern at the frequency of 2.6 GHz in the plane of xz and in the plane of yz is bi-directional. It can be observed that the difference in boresight direction of 18 dBi in the yz-plane and 10 dBi in the xz-plane of co-polarization and cross-polarization at the 2.6 GHz frequency. This result provides a linear polarization on both planes. As from Fig. 13(b) the antenna structure provides wave is LP in −z direction in the plane yz and the wave LP in +z direction and in xz plane. At θ = 0° provides a linear polarization in both the planes, the measured cross-polarization value greater than around 17 dB is observed.

5.4 The diversity performance

The performance of the diversity of a compact wang shape neutralization line has evaluated on parameters like diversity gain (DG) and envelope correlation coefficient (ECC). The parameter ECC 'ρ_c' is evaluated using Eq. (6) from S-parameters of the proposed structure. For better performance, the value of ECC is < 0.5 reported [8]. The simulated wang shape NL antenna ECC result is depicted Fig. 14. It would be observed that having the value lower than 0.021 over the entire dual-band resonant bands Fig. 14. depicts the desired value to be used in MIMO applications.

$$\rho_c = \frac{S_{11}^* S_{12} + S_{21}^* S_{22}^2}{\left(1 - S_{11}^2 - S_{21}^2\right)\left(1 - S_{22}^2 - S_{12}^2\right)} \quad (6)$$

The parameter DG is calculated from the S-parameters wherein the value of ECC is < 0.5 correspondingly its value is approximately equal to 10. The DG is evaluated by using Eq. (7) of wang shape NL line and depicted in Fig. 15. In this antenna at f = 2.1 GHz the ECC is 0.000572 and its DG is 9.9999, similarly at f = 6.1 GHz the ECC is 0.000195 and its DG is 9.9998 is observed. The

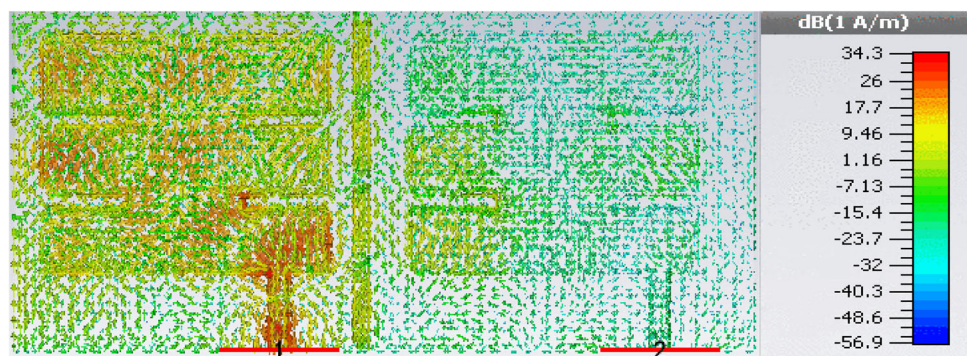**Fig. 10** Surface current distribution at port 1 f = 2.6 GHz

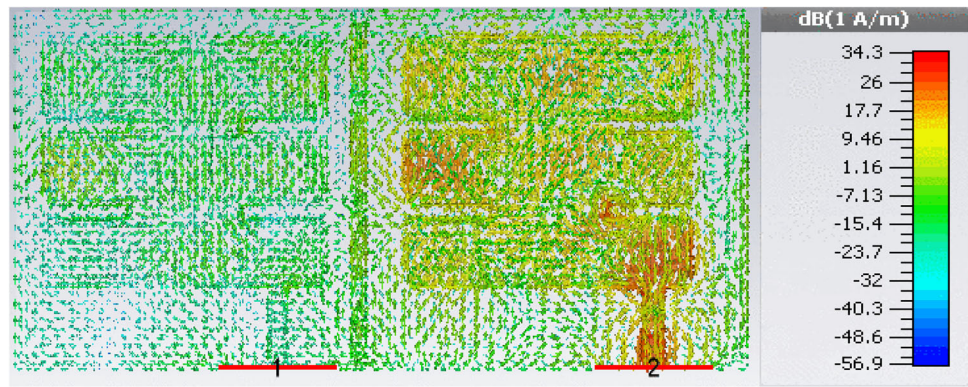**Fig. 11** Surface current distribution at port 2 f = 6.1 GHz

Fig. 12 Directivity, 3D, maximum value of proposed design

- - co polarization measured
- - cross polarization simulated

— co polarization simulation
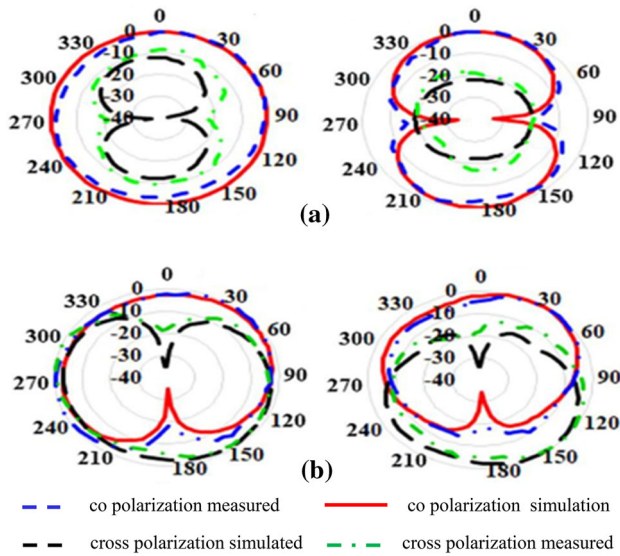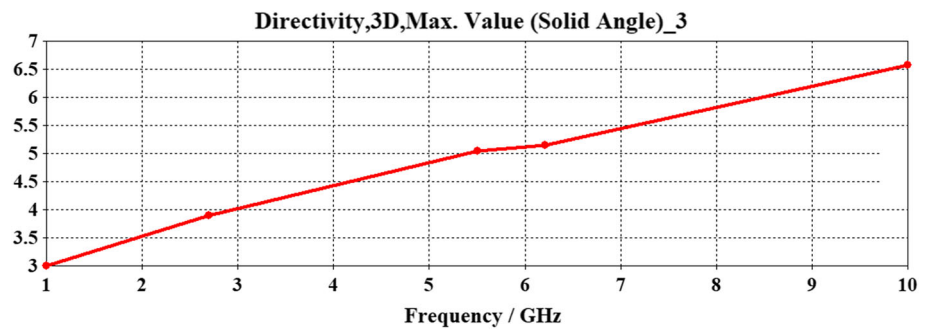-·- cross polarization measured

Fig. 13 The radiation pattern of wang shape neutralization line antenna **a** 2.6 GHz, **b** 6.1 GHz

simulated diversity gain is 9.9999 at 2.6 GHz and 9.9998 at 6.1 GHz. Finally noticed that measured and simulated parameter results are reasonably good agreement.

$$DG = \sqrt{1 - |\rho_c|^2} \tag{7}$$

6 MIMO parameters

The parameter of Total Active Reflective Coefficient (TARC) in terms of S-parameter is evaluated by using the relation is

$$TARC = \sqrt{|S_{11} + S_{12}e^{j\theta}|^2 + |S_{21} + S_{22}e^{j\theta}|^2}/\sqrt{2} \tag{8}$$

where θ variable range is 0 to 2π

Using the Rayleigh distribution function correlation coefficient mathematically represented as

$$\rho \approx |\rho_{cij}|^2 \tag{9}$$

For a system like N × N antenna analysis, ρ expressed interms of S-parameters

$$\rho(i,j,N) = \frac{\left|\sum_{n=1}^{N} S_{i,n}^* S_{n,j}\right|^2}{\prod_{k=i,j}\left[1 - \sum_{n=1}^{N} S_{k,n}^* S_{n,k}\right]} \tag{10}$$

Channel capacity is one of the important relation in any MIMO analysis because of how much amount of capability of the channel to acept a bandwidth is determined by the relation as

$$C = \log_2\left(\det\left(1 + \frac{SNR}{M}HH'\right)\right) \tag{11}$$

Finally the parameter capacity loss is determined by

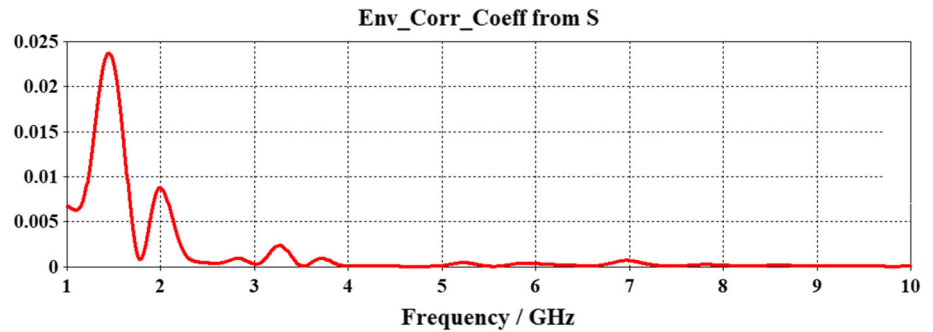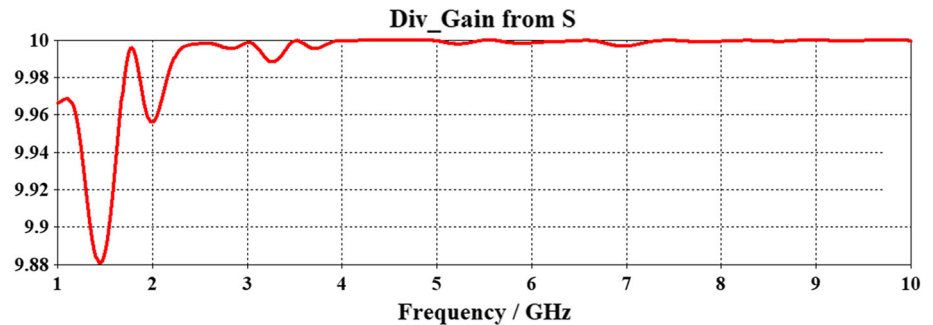**Fig. 14** Envelope correlation coefficient (ECC) of proposed structure

Fig. 15 Diversity gain of proposed system

$$C_{loss} = -\log_2 \det\left(\Psi^R\right) \tag{12}$$

$$\Psi^R = \begin{pmatrix} \rho_{1,1} & \dots & \rho_{1,N} \\ \vdots & \ddots & \vdots \\ \rho_{N,1} & \cdots & \rho_{N,N} \end{pmatrix} \tag{13}$$

$$\Psi^R = \begin{pmatrix} \rho_{11} & \rho_{12} \\ \rho_{21} & \rho_{22} \end{pmatrix} \tag{14}$$

$$\rho_{ii} = 1 - \left(|S_{ii}|^2 + |S_{ij}|^2\right), and\ \rho_{ij} = -\left(s_{ii}^* s_{ij} + s_{ij}^* s_{jj}\right),$$
$$for\ i,j = 1\ or\ 2 \tag{15}$$

where Ψ^R indicates the correlation matrix of receiving antenna.

To evaluate the potential of diversity antenna/MIMO, ECC (envelope correlation coefficient) is a major criterion to be presented. Basically, ECC can be calculated by using radiation pattern or S-parameters of the antenna. In the proposed structure the value of ECC is around 0.000572 at 2.6 GHz and 0.000195 at 6.1 GHz these values are good for the proposed design of dual-band structure in the applications of WiMAX, 2.6 GHz UMTS and C-band 6.1 GHz. There is an improvement of ECC can be observe that after inserted the neutralization line it fulfils the diversity value is < 0.5. Therefore, the design structure is a good candidate for the MIMO applications.

It can be identify that inserting the neutralization line method the capacity loss neither exceed 0.36 bps/Hz at 2.6 GHz and 0.28 bps/Hz at 6.1 GHz is suitable for the design of MIMO antenna in the applications of WiMAX, 2.6 GHz UMTS and C-band 6.1 GHz. The parameter of channel capacity using neutralization line method is 3.975 bits/s/Hz at 2.6 GHz and 3.684 bits/s/Hz at 2.6 GHz is enough to operating of proposed MIMO structure for the applications WiMAX, 2.6 GHz UMTS and C-band 6.1 GHz. Similarly another parameter TARC (total active reflection coefficient) good performance is obtained using neutralization method − 32.76 dB at 2.6 GHz and − 29.35 dB at 2.6 GHz. Finally, we concluded that the MIMO parameters shows lower loss of channel capacity, capacity loss, ECC and good performance of TARC suitable for the application of WiMAX, 2.6 GHz UMTS and C-band 6.1 GHz (Table 3).

7 Conclusions

A wang shape neutralization line linearly polarized microstrip-fed dual-band radiator for wireless applications is demonstrated here. The procedure involves cutting two rectangular slots in the patch of the left side and right side of the patch to form a wang shape antenna. A neutralization line is inserted between the patches to reduce the mutual coupling to achieve dual-band polarization. Whereas the measured wang shape antenna as −10 dB Impedance Bandwidths (IBWs) of 1.02 GHz (2.23–3.25 GHz) and 900 MHz (5.70–6.60 GHz) having the wide dual-band functionality, linear polarization band, easy structure with better radiations, thus making it an ideal candidate for

Table 3 Comparison of proposed antenna MIMO parameters

S. no.	Frequency (GHz)	Correlation coefficient (ρ)	TARC in dB	Channel capacity (bits/s/Hz)	Capacity loss in (bits/s/Hz)
1	2.6	0.000572	− 32.76	3.975	0.36
2	6.1	0.000195	− 29.35	3.684	0.28

different applications like WiMAX, 2.6 GHz UMTS and C-band 6.1 GHz.

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